A study of $b\overline{b}$ production mechanisms in PYTHIA ‡

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Abstract. The influence of the $\hat{P}_t$ cutoff on the production of $b\overline{b}$ events in Pythia has been studied. Two samples of events generated with $\hat{P}_t \geq 1 GeV$ (default) and with $\hat{P}_t \geq 10$ GeV are investigated. In versions 5.75 and 6.115 of Pythia there are some critical differences between the two samples for what concerns contribution in $b\overline{b}$ production mechanisms. Version 6.152, taken as the CMS official one, has been tested also.

1. Introduction

CMS (Compact Muon Solenoid) is a general purpose experiment under construction at CERN. The description of the apparatus is given elsewhere [1]. CMS will be built on LHC (Large Hadron Collider) a *pp* collider with $\sqrt{s}$=14 TeV and a maximum luminosity of $10^{34} \, cm^{-2} \, s^{-1}$ [2] . One of the main physics topics of the Collaboration will be the study of the B hadron physics. In fact apart from the interest "per se" of this topic, b-jets are also the main background for several other physics channels [3], [4]. In this article, I present a study on $b\overline{b}$ production mechanisms at LHC energies using the Monte Carlo package Pythia [5] as event generator.

At a hadron collider $b\overline{b}$ pairs are produced by the following mechanisms:

(i) **Pair production** (gluon or quark fusion): $gg \rightarrow b\overline{b}$, $q\overline{q} \rightarrow b\overline{b}$. For each event a $b\overline{b}$ pair is produced in the hard interaction.

(ii) **Flavour excitation**: $bq \rightarrow bq$, $bg \rightarrow bg$. A heavy flavour from the parton distribution of one beam particle is put on mass shell by scattering against a parton of the other beam. As b quark is not a valence flavour it must come from a branching $g \rightarrow b\overline{b}$.

(iii) **Gluon splitting**: $g \rightarrow b\overline{b}$. It occurs in the initial- or final-state shower but no heavy flavours are produced in the hard scattering.

A more detailed definition of the mechanisms can be found in ref [6]. As these mechanisms give rise to different kinematic configurations of the final state is important to understand their contribution to the total cross section.

The only way to generate (i), (ii) and (iii) in Pythia is using the steering card MSEL=1,

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which generates QCD 2 $\rightarrow$ 2 events. In order to have higher statistics, and save computation time the user can set kinematic cuts at generation level which limits the available portion of phase space [7], increasing the efficiency of selection cuts. One of this cuts is the $\hat{P}_t$ cutoff. ‖

In the following sections I will show differences between the use of the Pythia default cutoff (1 GeV) and a 10 GeV cutoff. Three versions of the generator have been considered: 5.75, 6.115 and 6.152 which has been chosen as event generator for the next CMS physics studies.

2. $b\bar{b}$ production cross sections

Two samples have been prepared with the three versions of Pythia to investigate the influence of the $\hat{P}_t$ cutoff on the production of $b\bar{b}$ events. Both of them have been generated using MSEL=1 and contain events with only one $b\bar{b}$ pair. The first sample (SAMPLE A) has been generated with the default $\hat{P}_t$ cutoff (1 GeV). The second sample (SAMPLE B) has been generated with $\hat{P}_t \geq 10$ GeV. For both samples the $b\bar{b}$ production cross section for $\hat{P}_t \geq 10$ GeV has been computed using the following formula:

$$\sigma_{b\bar{b}}^{(\hat{P}_t \geq 10 \ GeV)} = \frac{N_{b\bar{b}}^{(\hat{P}_t \geq 10 \ GeV)}}{N_{tot}} \cdot \sigma_{tot} \tag{1}$$

where $N_{b\bar{b}}^{(\hat{P}_t \geq 10 \ GeV)}$ is the number of $b\bar{b}$ events with $\hat{P}_t \geq 10$ GeV, N^{tot} is the total number of events generated and σ^{tot} is the total (QCD 2 $\rightarrow$ 2) cross section given by Pythia . The results of the computation for the three versions of the package are shown in Tab.1 (the values of the cross section are given in μb).

cross section ($\hat{P}_t \geq 10$ GeV) (μb)	P 5.75		P 6.115		P 6.152	
	A	B	A	B	A	B
σ pair production	20	20	47	51	48	52
$\sigma_{\text{flavour excitation}}$	-	110	-	221	211	236
$\sigma_{\text{gluon splitting}}$	130	130	173	193	159	173
$\sigma_{b\bar{b}}$	150	260	220	465	418	461

Table 1. Contributions to the $b\bar{b}$ production cross section for $\hat{P}_t \geq 10$ GeV with Pythia 5.75, 6.115 and 6.152 (in μb).

All double countings have been avoided requiring the number of b-quarks coming from the hard interaction to be 2 (pair production), 1 (flavour excitation) or 0 (gluon splitting). As it appears clear from the table for version 5.75 and 6.115 the cross section is $\hat{P}_t$ dependent. The problem is related to flavour excitation which in this two

‖ $\hat{P}_t$ is defined as the transverse momentum of the outgoing partons in the center of mass system of the ingoing partons.

versions cannot be generated with default $\hat{P}_t$ cutoff (sample A). The difference in the $\sigma_{b\bar{b}}$ (for sample A) between 5.75 and 6.115 is due to the different choice of the default parton distribution function. The interpretation of the observed phenomena, given by T. Sjöstrand and E. Norrbin, is reported in [8]. In version 6.152 the problem related to flavour excitation has been set but there is still a difference of about 10% between the cross sections of the two samples (for all versions statistical errors can be neglected).

The difference in the value of cross sections is not very important, because the results are usually normalized to the total $b\bar{b}$ cross section of 500 μb. On the other hand, the different contributions for the production mechanisms could be more dangerous, as they can lead to different kinematic distributions, and therefore affect the efficiencies for different selections.

Fig. 1 illustrates the difference in the $b\bar{b}$ production cross sections due to the additional contribution of the flavour excitation mechanism in sample B.
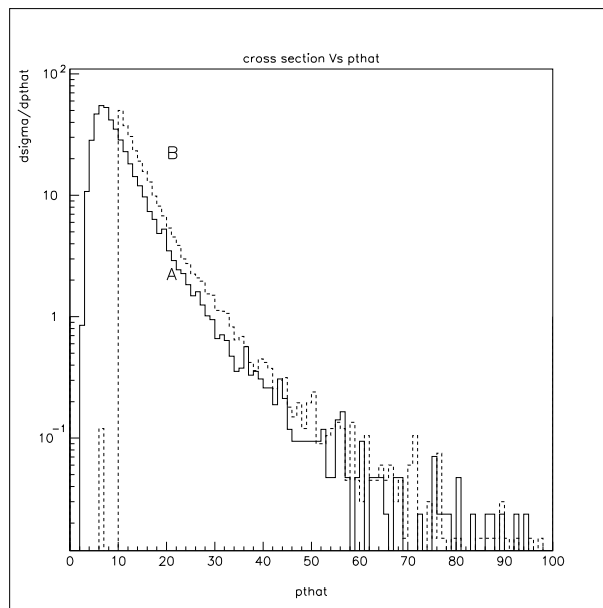

Figure 1. Cross section with the two different cutoff on $\hat{P}_t$. The solid line is with the default cutoff (1 GeV). The picture is obtained with Pythia 5.75.

3. Kinematic distributions

The main kinematic parameters which define the signature of $b\bar{b}$ event are the transverse momenta and pseudorapidities of the b quarks, and the angular distance $\Delta\phi$ between their directions in the transverse plane. The first two parameters have similar distributions in both samples. The $\Delta\phi$ distribution is shown in fig. 2 for the three different mechanisms. For what concerns gluon splitting, the distribution is slightly peaked at small $\Delta\phi$. The angle between the two b-quarks produced by the gluon-fusion
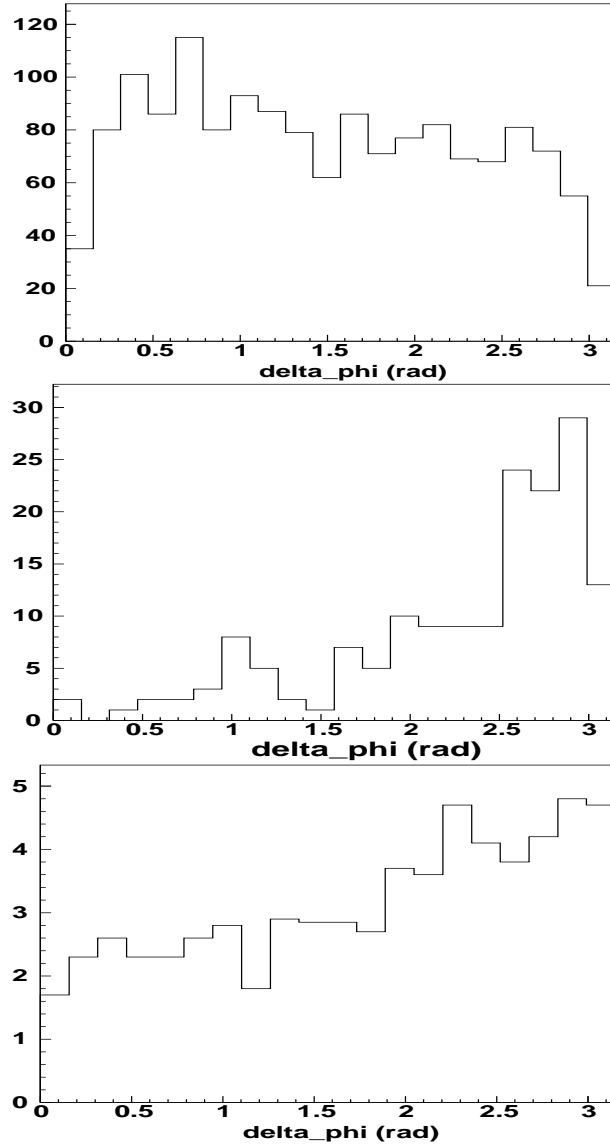
Figure 2. Distribution of the angle between the two b quarks in the transverse plane: the upper one is gluon splitting, the middle is gluon fusion, the last is related to flavour excitation. The plots are in arbitrary units.

mechanism has a peak at $\Delta\phi \sim \pi$, as expected, since in the process $gg \rightarrow b\bar{b}$ the b-quarks are produced back-to-back in the transverse plane. The last distribution corresponds to the flavour excitation production mechanism, for which the back-to-back topology is preferred. We can conclude that the total $\Delta\phi$ distributions of sample A and sample B are slightly different. Some care should be taken about this, as it could affect the estimated efficiency of selection cuts.

4. Conclusions

Versions 5.75 and 6.115 show a big discrepancy in the total $b\overline{b}$ production cross section when using two different cutoffs on $\hat{P}_t$. The problem is due to flavour excitation which can be generated only in sample B but gluon splitting and pair production are stable and show the same cross section in the two samples. In both versions the use of a different $\hat{P}_t$. cutoff from the default one leads to slightly different $\Delta\phi_{b\overline{b}}$ distributions caused by the presence of flavour excitation.

In version 6.152 everything is set, a part a little inconsistency of about 10% on which I am working in order to understand the cause.

5. Acknowledgements

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